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HUMANE CROWD DISPERSAL: PULSED JET WATER CANNON

Final Report

By

EXOTECH INCORPORATED
1200 Quince Orchard Boulevard
Gaithersburg, Maryland 20760

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13. ABSTRACT

An experimental water jet system was developed and tested as a humane method of crowd control. Gas pressure was released behind a column of water to eject it through a nozzle as a pulse instead of a steady stream. Several nozzle diameters, water quantities, and pressures were tested. The best effectiveness was achieved with a 1 3/8-inch diameter nozzle, 1 1/2 gallons of water, and 175 pounds per square inch. The total range was 150 feet, and the range at which people would be unwilling to approach closer was 90 feet. The experimental system was capable of producing only single shots.

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INTRODUCTION

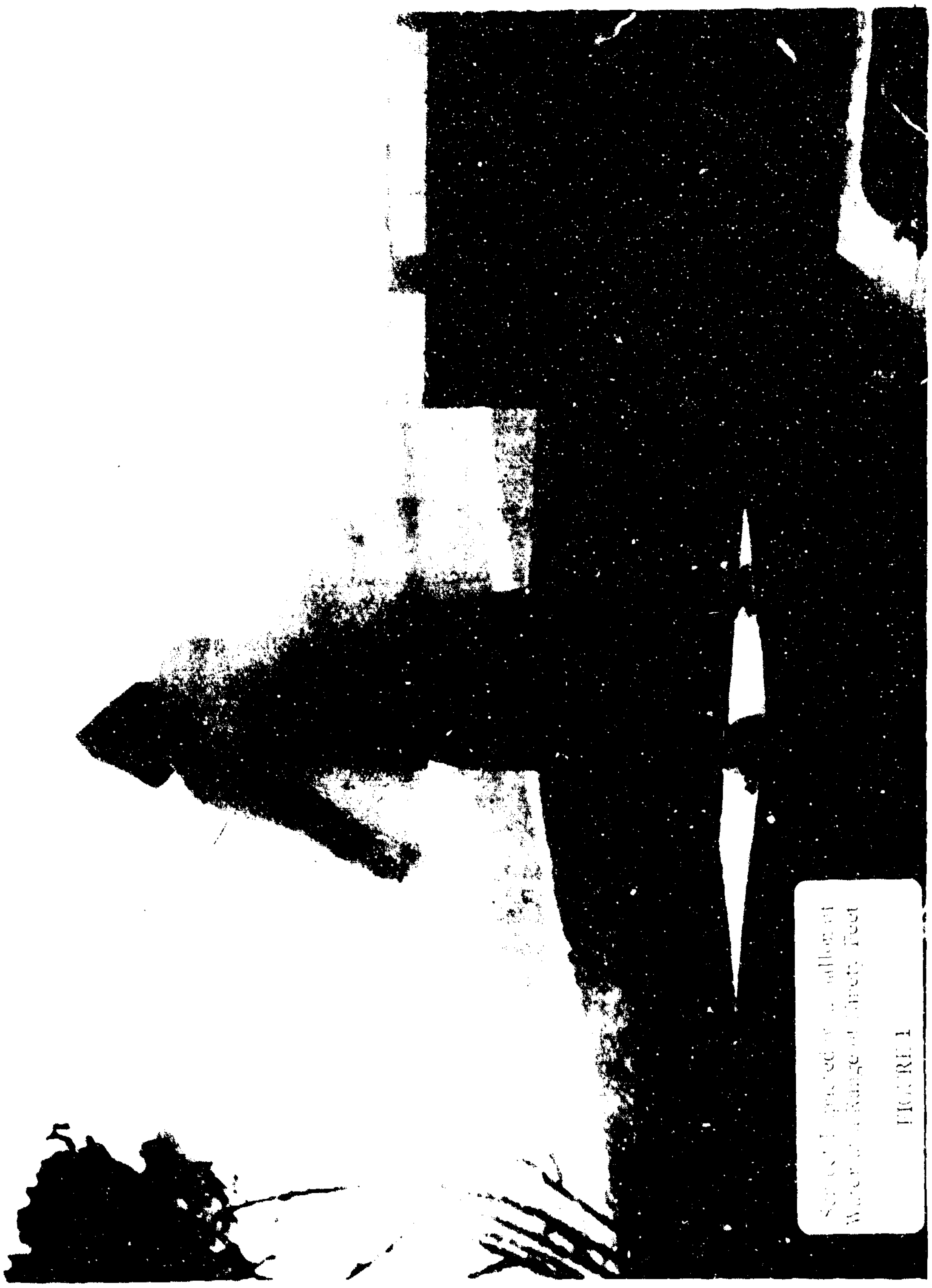
WHY PULSED WATER JETS

One of the most effective methods of crowd dispersal used today is a cold shower at the end of a fire hose. This method has been used in this country and abroad but has as its chief disadvantage a great consumption of water which literally "ties" the pumping unit to a hydrant or other large source of water. If, however, the water is pulsed as rods instead of a steady stream, much less water is required making possible a mobile vehicle which is more adaptable to any area in which a disturbance may occur.

When dispersing a crowd which is determined to stay put, a low pressure water jet becomes an ideal tool. Water has many properties over other control methods, including the following:

1. Easy to control — turn off and on by switch
2. Leaves area unaffected once turned off
3. Directional — will not stray into undesirable areas
4. Non-toxic
5. Plentiful and inexpensive
6. Readily available
7. Additives can be used if desired.

Another benefit of this type of system is to "forewarn" a group of the severity of the possible power of a water jet. At 150 feet, the water pulse would fall like rain but as the range becomes shorter, the water's force gradually goes up. At 90 feet, subjects report the effect as "being hit in the back by a board." Closer ranges become increasingly uncomfortable as discussed in the test results.



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THE DEMONSTRATION EQUIPMENT

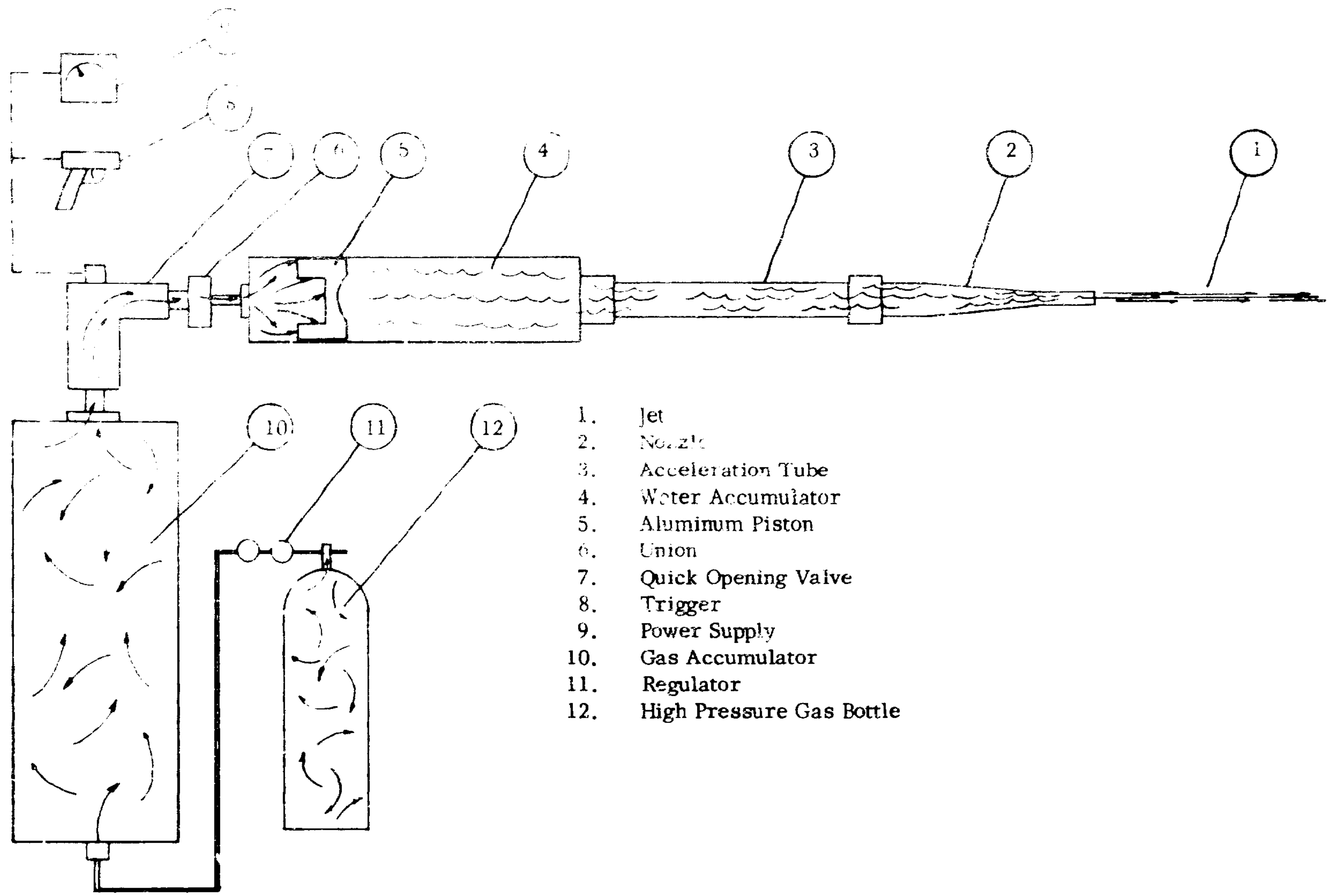
THE EVOLUTION OF THE DEMONSTRATION SYSTEM

During the early stages of the program, a number of variations of equipment were used to achieve the greatest water jet range. These included metallic as well as gas pistons forcing the water through a variety of nozzles.

It should be kept in mind that the objective of the program was to assemble a system capable of demonstrating the effectiveness of small bursts, or pulses, of water for use in crowd control. The system was to be geared to a prototype while demonstrating the jet range coherence and impact effect. The first system tested used accumulators with light weight aluminum pistons to force water through an acceleration tube and nozzle. Figure 2 depicts this system. The gas storage accumulator typically held between one-half and one cubic foot of compressed gas while the water storage accumulator was varied from one-half to two and one-half gallons capacity. The acceleration tube was varied from six inches to three feet. The nozzle tip diameter was one of four sizes: 3/4" I.D., 1.0" I.D., 1-3/8" I.D., and 2.0" I.D.. Gas pressure used to accelerate the piston ranged from 50 to 500 psi. Above 500 psi, the jet issued as a spray

The acculator system operated as follows: once the water storage and compressed gas units were charged, the system was activated by a "trigger" opening the fast acting solenoid valve and dumping gas behind the aluminum piston. While this system was very effective, it necessitated the stopping of the piston, retraction of the piston, and probably maintenance difficulties on the piston seals due to the fast operational cycles.

Once the best jet results and system were attained, the system was gradually simplified. First, the piston was removed from the water storage accumulator and the water forced from the accumulator by the compressed gas alone. Eventually, the system was simplified to loading a seven foot long $2\frac{1}{2}$" I.D. steel pipe with water and dumping gas behind the water. This system is described in the next section. Results from this combination matched those using metal piston accumulators while having the tremendous benefit of no moving parts other than the fast acting dump valve common to both setups.



Pulsed Water Jet System Using Accumulators for Producing the Water Pulse

FIGURE 2

THE DEMONSTRATION EQUIPMENT

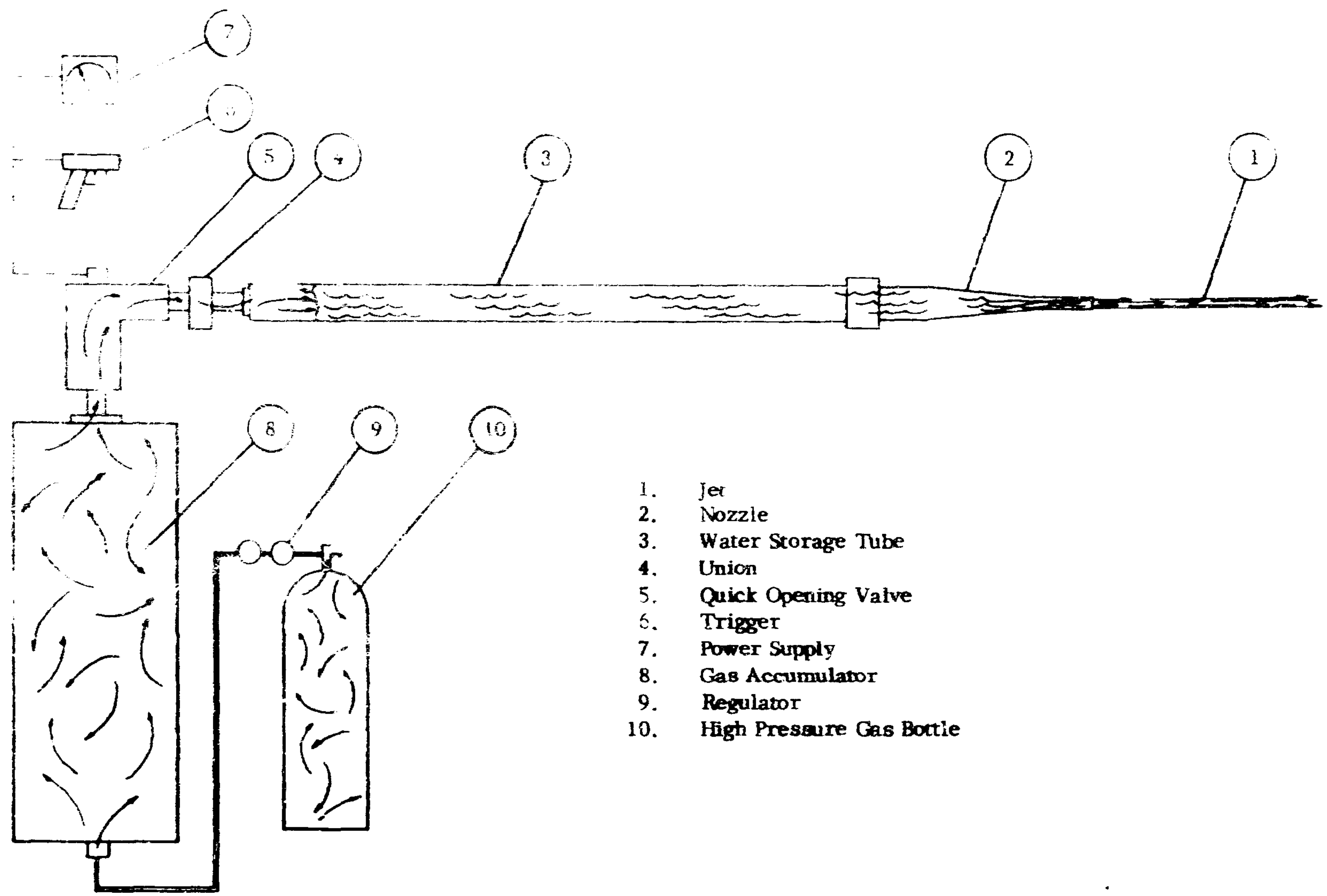
A SIMPLE SYSTEM TO DEMONSTRATE THE EFFECTIVENESS OF PULSED WATER JETS

The basic design used was simple, economical, and flexible and provided a test bed for studying the effects of various operating conditions on the water jet produced.

The design settled upon for the pulsed jet device is shown schematically in Figure 3. Our objective was to provide a demonstration system to show the effectiveness of large pulsed jets and determine the best parameters to be used in building the prototype device. Several different systems were explored and tested. The system settled upon was the most effective, simplest, and most easily adaptable to a fully operational prototype.

In this system, the propulsion force was compressed gas (dry nitrogen or air) loaded into a one pulse accumulator. Bottled gas at 2000 psi was regulated down to the test pressures ranging from 50 - 500 psi. The water storage tube was seamless steel pipe with a $2\frac{1}{2}$" I.D. and 3" O.D. The pipe length was varied to give volumes of 1, $1\frac{1}{2}$ and 2 gallons. The fast acting valve used was a Marotta Model MV121 with a port size of approximately 0.8 inches.

To operate, the accumulator was filled with compressed gas at the desired pressure and the water loaded through the nozzle into the water storage tube. The system was triggered by activating the solenoid valve. The valve operated from fully closed to fully open in 5 milliseconds. The gas expanded through the valve and accelerated the water out of the nozzle. Although mixing of the gas and water was feared, this did not occur to any significant degree. With this system, no metallic pistons are required to be stopped, retracted or its seals maintained. Releasing the trigger closes the valve and the system is ready for another charge of gas and water.



Pulsed Jet System Using the Compressed Air Slug as a Piston

FIGURE 3

EXPERIMENTAL RESULTS

HOW THE NOZZLE TIP DIAMETER AND WATER VOLUME WERE SELECTED

Nozzle tip diameters were varied from three quarters of an inch to two inches. Water volume was increased from one-half gallon to two gallons. The optimum results were achieved with a nozzle of 1-3/8" tip diameter and a water volume of approximately $1\frac{1}{2}$ gallons.

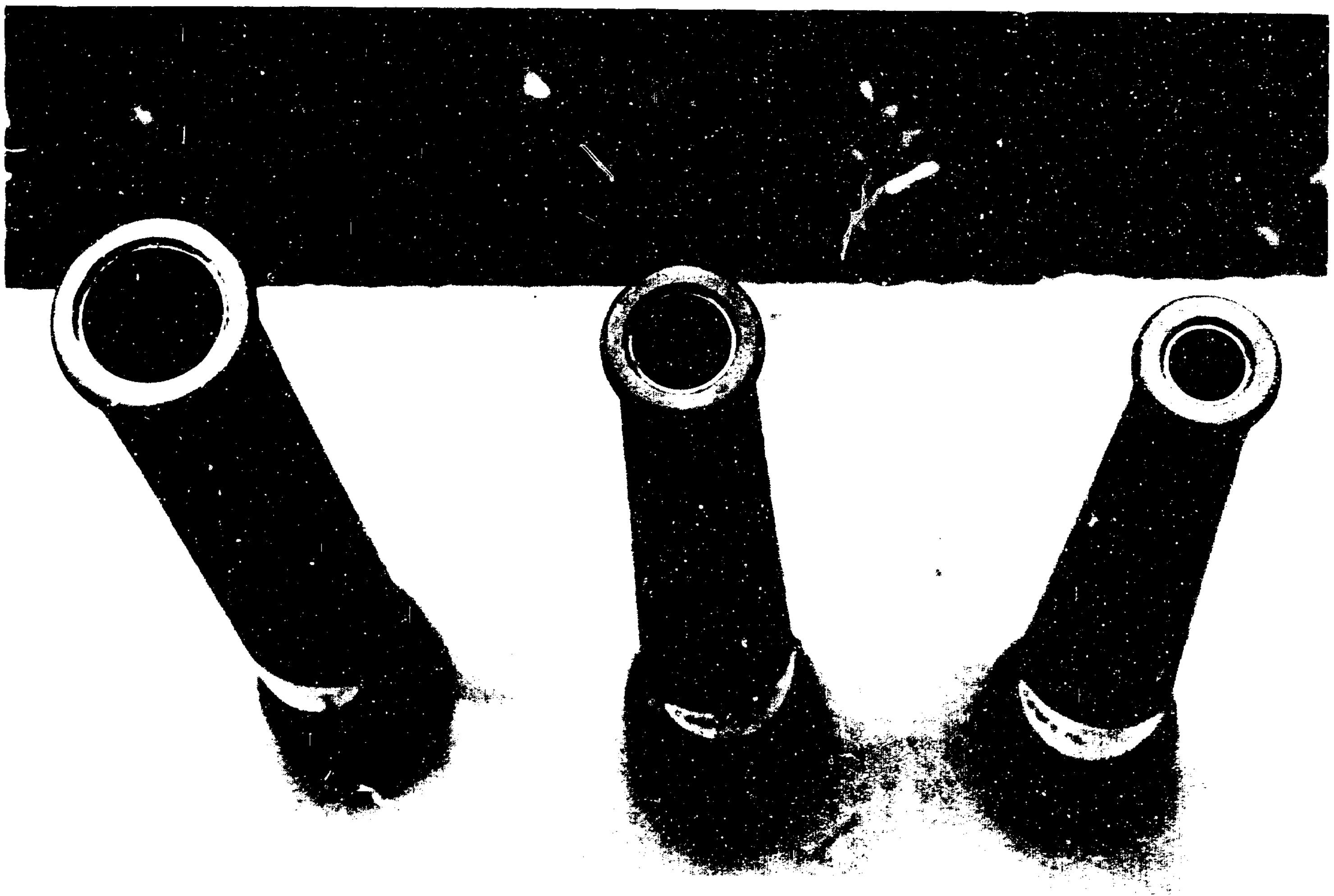
Using the gas piston concept, that is, a slug of compressed air to force the piston from the water storage tube, a series of nozzles and water volumes were investigated. Of the four nozzle sizes tested (3/4", 1.0", 1-3/8", 2"), the 2" diameter nozzle was the only one which gave consistently poor results at all pressures. This nozzle produced a jet with a lower velocity and shorter core which tended to disintegrate quickly into a heavy spray with a range of approximately 75 to 100 feet. Figures 4 and 5 show the geometry of three of the nozzle sizes used.

The 3/4" nozzle gave a longer core than the other nozzles but the pressure buildup in the nozzle due to the sudden pressure surge eventually caused the nozzle to fail. The 1.0" and 1-3/8" diameter nozzles gave very close results. The 1-3/8" nozzle was selected as a potential prototype size due to its ability to deliver more effective impact pressures to a target. However, interchangeability of nozzles can be easily carried out with the suggested prototype system. Therefore, longer jets from smaller nozzles than 1-3/8" tip diameter can readily be achieved if desired.

Water volume was varied from one-half to two gallons in half gallon increments. This was done by gradually increasing the length of the $2\frac{1}{2}$" I.D. steel water storage tube. With the nozzles used, the most effective volumes were between one and one and a half gallons. One half gallon produced too short a jet while two gallons did not appear to give any better target impact than one and a half gallons. Since one of our goals was to use the least water that could be used effectively, the volume settled upon was one and a half gallons.

Side View of Three of the Test Nozzles: Left to Right - 1", 1-3/8", 2" - Tip Diameter

FIGURE 4



Viewing the Tip of Three of the Test Nozzles: Left to Right - 2", 1-3/8", 1" - Tip Diameter
FIGURE 5

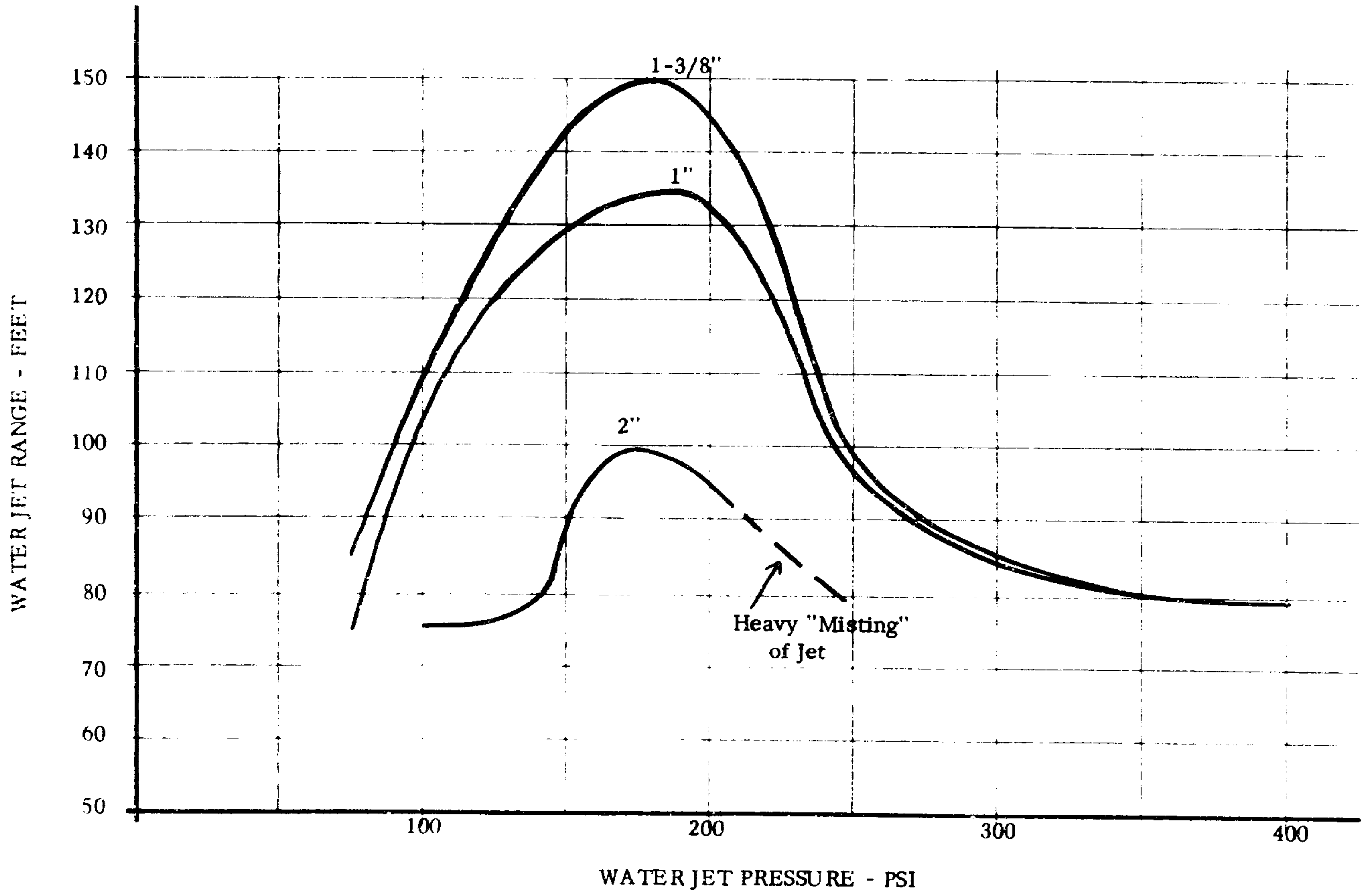
EXPERIMENTAL RESULTS

HOW THE GAS DRIVING PRESSURE EFFECTED THE WATER JET PERFORMANCE

Generally, the jet range and coherence increased with gas driving pressure up to a point. Once the best pressure was reached, however, jet range decreased with greater gas pressures. The optimum pressure appears to be between 150 and 180 psi and with the proper nozzle and volumes give jet ranges of up to 150 feet.

To determine the effects of gas pressure, the system was fixed as to plumbing, water volume, gas volume and nozzle size. The gas pressure was then varied from 50 to 500 psi and the effects on jet range and coherence observed. One of the first difficulties found was the shrouding of the main "jet core" by a surrounding mist. Depending on the viewing angle, different estimates of jet range were recorded. The best method determined to evaluate the jets performance was recording the jets actions on movie film and viewing the results using a stop action analytical projector. This was done with a film documenting the test conditions furnished along with this report. Of course, the ideal way is to pulse the jet at a volunteer and record his impressions. Both methods were used and the "human recorders" results discussed in a later section. Figure 6 shows the effects of gas driving pressure on jet range. As can be seen, the best range appears to be approximately 175 psi. One thing should be noted about the testing conditions: during many of the tests, wind was blowing up to 20 - 30 mph in gusts. The effect of a crosswind can be severe on the overall jet performance in regard to both range and coherence.

While jet pressures much above 175 psi tend to cut the jet's range, there may be situations where higher pressures would be desired at point blank range. Dislodging barricades may be required in some situations and at those times, a high pressure jet at short range may be highly desirable. While this may be a tactical desirability, it is felt that pressures much above 400 - 500 psi will not be required.



Effect of Compressed Gas Pressure on Jet Range

FIGURE 6

EXPERIMENTAL RESULTS

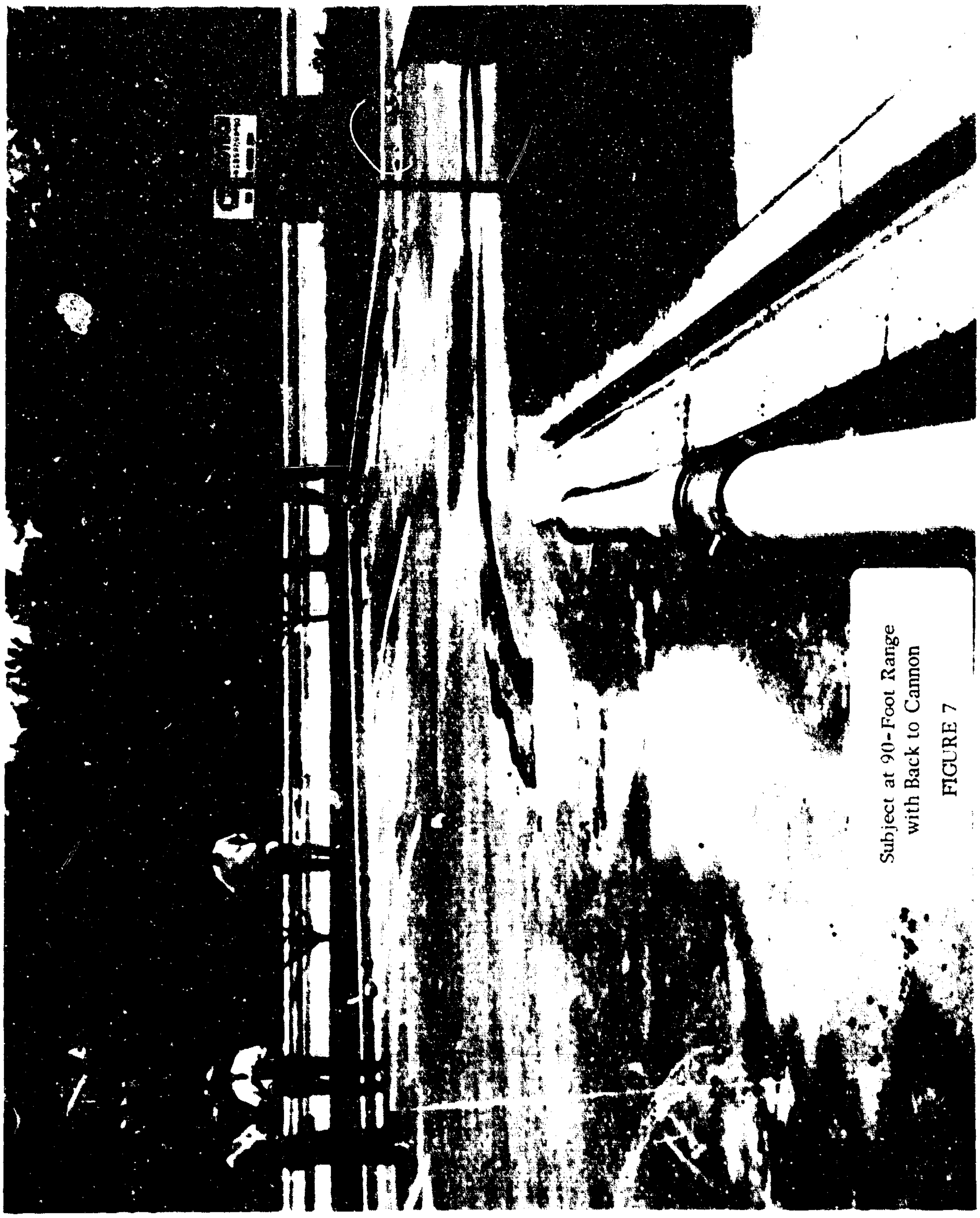
THE EFFECT ON TARGETS BY PULSED JETS

Once the system was fixed, several wooden targets were subjected to jet pulses at different ranges. Project personnel from Aberdeen were wet down with the jets at the longer ranges but declined to come any closer than 85 - 90 feet.

The system goal was a "wet down" capability of approximately 150 feet with gradually increased impact pressure until "knock down" was achieved at approximately 50 feet. Wooden targets the size of a man were impacted at ranges from 20 to 100 feet using a variety of driving gas pressures. At a pressure of twenty feet, a target weighing 150 pounds was flung back five feet and tipped over. However, the gas pressure could be easily regulated down to a pressure where the target was merely "drenched" without any high impact pressure. The target moved back to sixty feet resulted in approximately a backward push of a foot. However, at 180 psi gas driving pressure, it is believed that the jet at a sixty foot range would certainly knock a man off his feet and could cause some harm if the jet impacted a person in the face. Here again, by simply reducing the jet pressure, the subject could be wet down without being subjected to substantial force.

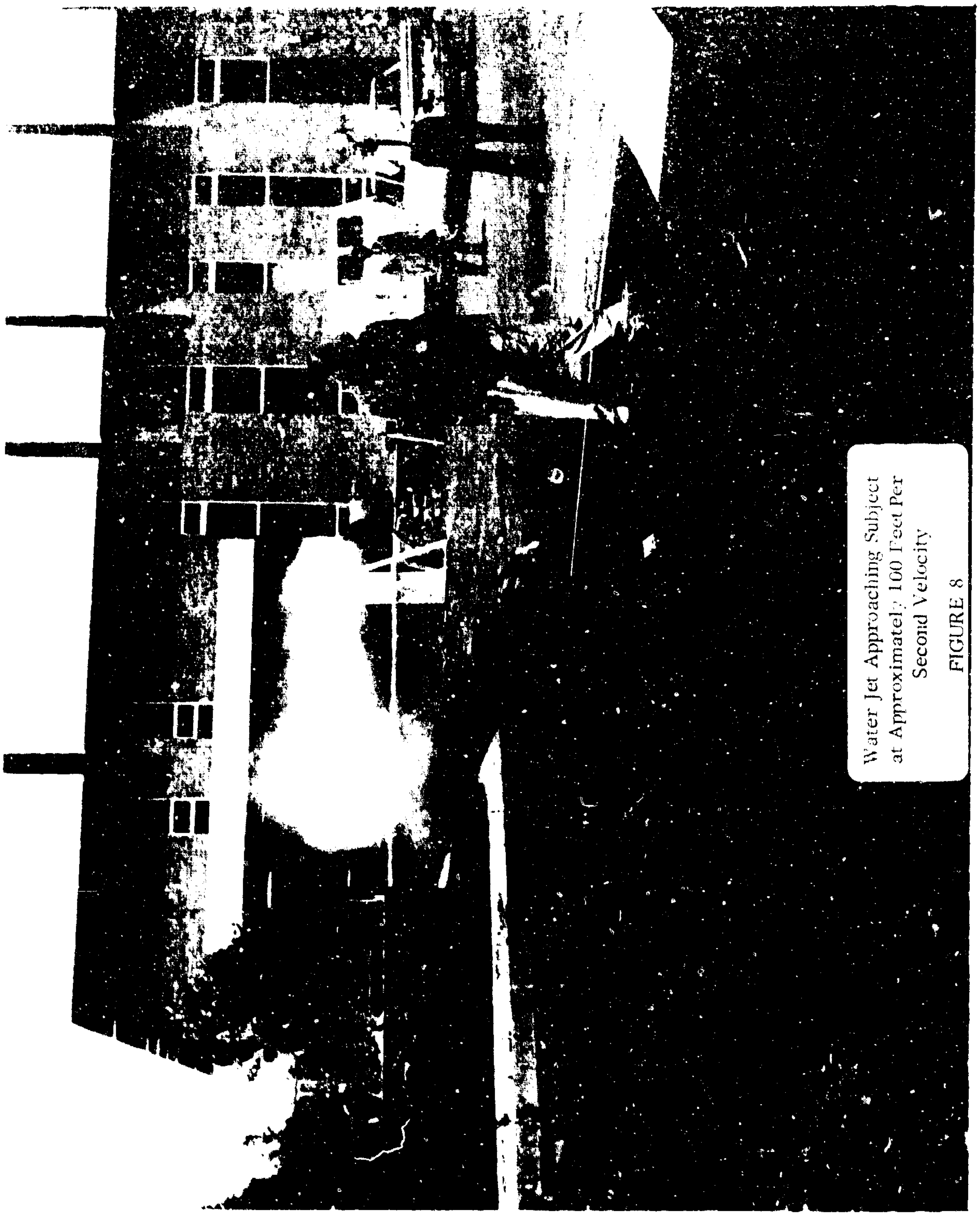
Several project members from the Aberdeen Proving Ground allowed themselves to be subjected to the jet pulses while movies were taken. By starting at approximately 150 feet and working in, they could gage the severity of the jet's force. The subjects were completely clothed in foul weather gear and were hit in the back only, never in the face. By the time the range had closed to approximately 100 - 105 feet, the discomfort was becoming apparent. Between 100 and 85 feet the severity of the jet impact increased to the point that they did not want to come any closer. One subject described the effect as "being hit in the back with a board." Figures 7 through 10 show a sequence of a subject being hit with a gallon of water at a driving gas pressure of 180 psi at a range of approximately 90 feet.

Ranges closer than 85 feet would rapidly increase the jet effectiveness if the pressure was set at 180 psi. However, close range tactics could easily be developed using lower pressures or simply directing the jet to impact just in front of the subject with the pavement absorbing a great deal of the force and the subject receiving the reflected spray.



Subject at 90-Foot Range
with Back to Cannon

FIGURE 7



Water Jet Approaching Subject at Approximately 100 Feet Per Second Velocity

FIGURE 8

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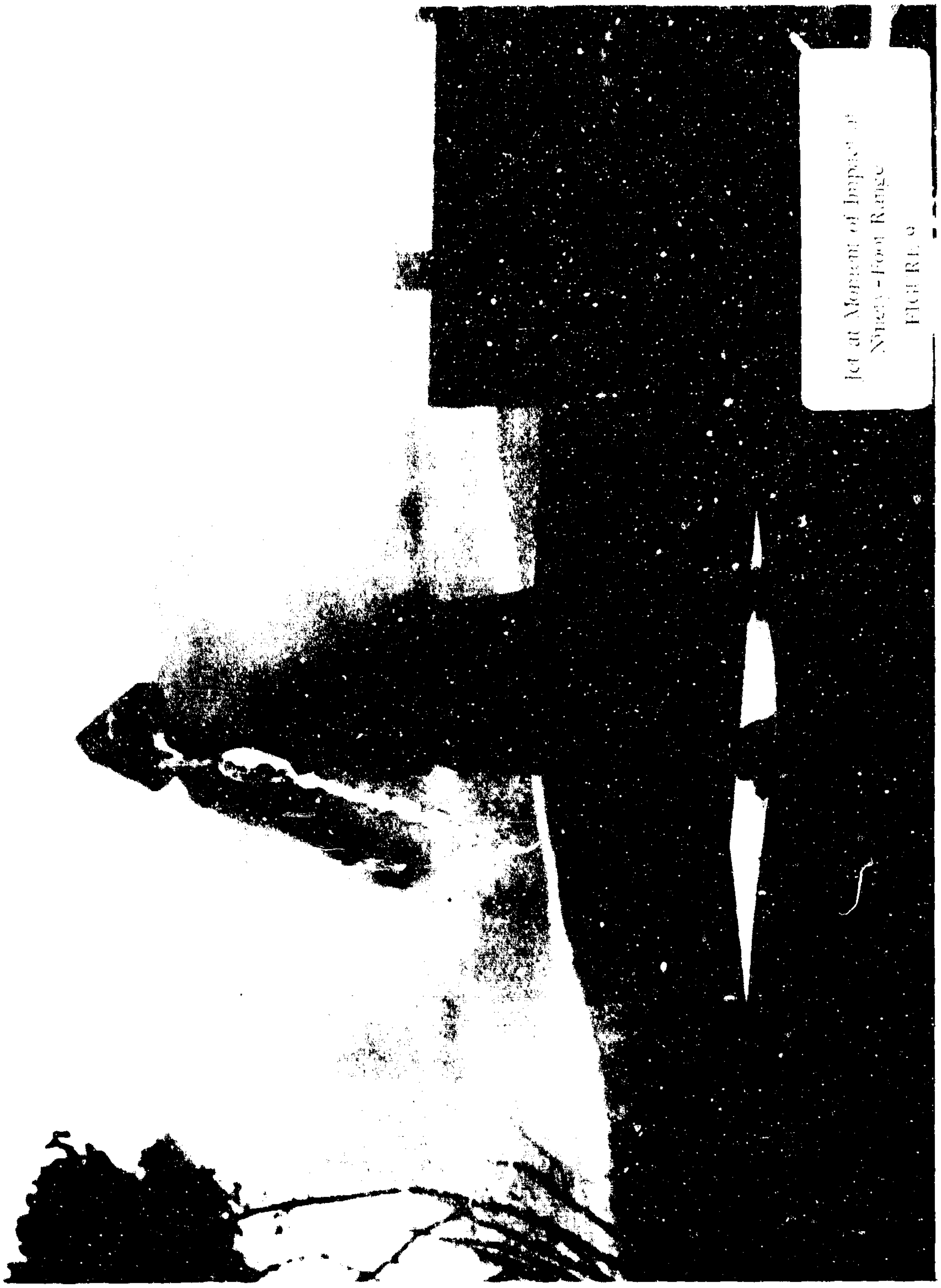

Jet at Moment of Impact at Ninety-Foot Range

FIGURE 6

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Side View of Subject Being
Impacted at a Ninety-Foot Range

FIGURE 10

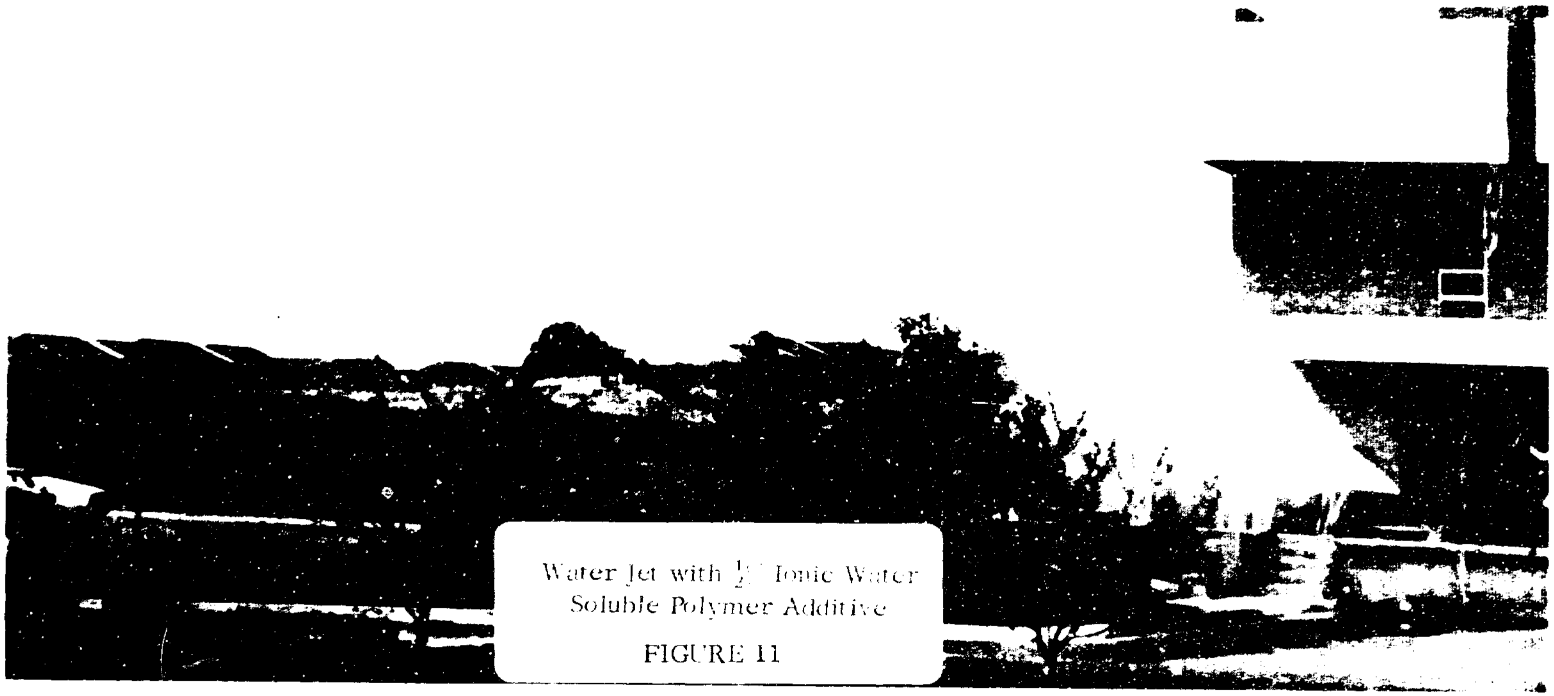
EXPERIMENTAL RESULTS

THE EFFECT OF ADDITIVES TO THE WATER

Although one of the prime reasons for using water is its absence of toxic agents, in some instances, it may be desirable to add material to give the water different characteristics. Materials which improve the jet coherence while making the water slippery, more viscous and unpleasant have been tested. Other additives, such as dyes for identification, can easily be injected into the water system without causing harm to subjects.

While water has practically all the desired safeguards for crowd control, i.e., off-on control, non-contamination, accuate directional control, gradual severity levels, easy control, and others, there may be times when addition of material to the water is desirable. To determine the effects on water jet range, coherence and target impact, we added an ionic water soluble polymer to the water at a $\frac{1}{2}\%$ and 1% weight level. The resulting material easily poured while being "slick and stringy" to the touch. Although jet range was not noticeably improved, the water definitely was more coherent even at the farthest ranges. Figure 11 shows the jet with an additive at a range of approximately 100 feet. Most of the water that would have fallen as a spray, fell instead in large tear shaped "blobs." There was no question that the additive made the water much more obnoxious to subjects. The material used is being approved by the FDA as acceptable in food processing.

The one main problem with the additive is that it contaminated the residual water left on the ground. Footing and driving could be a hazard until the solution was forcibly washed away. The treated water tended to stick to surfaces and would not evaporate to any degree. Another consideration with the material would be the added cost, approximately one dollar per 200 pounds of water treated, and the added equipment for mixing the additive with the water. The mixing equipment, however, is not expected to add much expense when incorporated into a system.



Water Jet with $\frac{1}{2}$% Ionic Water Soluble Polymer Additive

FIGURE 11

THE PROTOTYPE SYSTEM

THE NEXT LOGICAL STEP IN DEVELOPING THE MOBILE SYSTEM

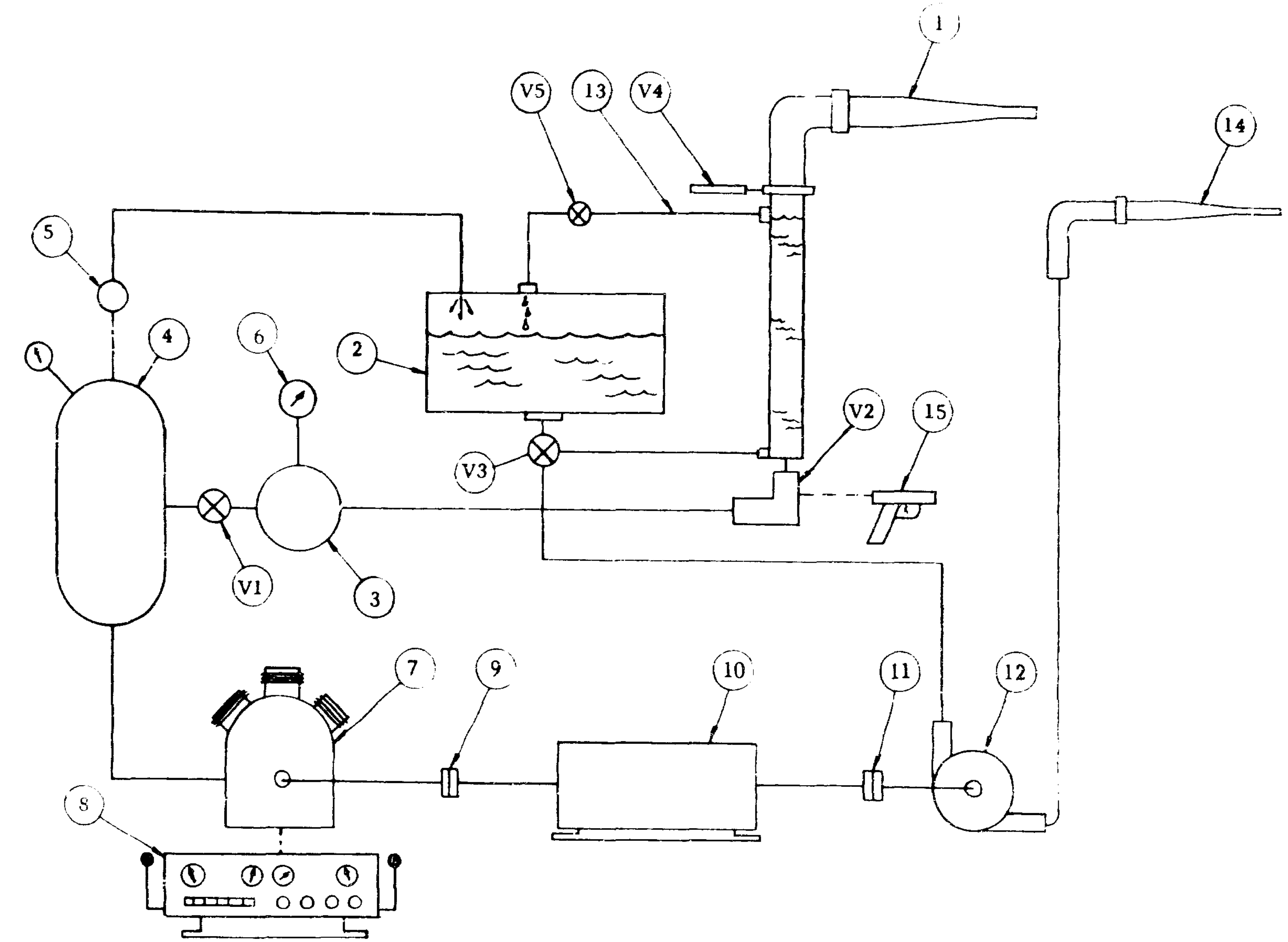
Before outfitting vehicles with this system, a skid mounted prototype is recommended. This system should be capable of producing pulsed or continuous jets and be as close to the final mobile unit needs as possible.

A conceptual design of a suggested automatic system is outlined in Figure 12. This system would be capable of operating in either a pulsed or steady stream mode. This gives operational options that are desirable to meet most situations that are anticipated in crowd control and still have all the benefits required for a highly mobile system. The system has the general characteristics of pulsing at the rate of once every two seconds while producing a jet of approximately $1\frac{1}{2}$ gallons at 175 psi. The system would operate in a steady jet mode producing a jet out of a one-half inch nozzle at 150 psi. This size is reportedly used in the water cannons used in Europe.

Basically, the system works as two separate systems "clutched" together to a common prime mover. Normally, the motor drives an air compressor to supply the necessary driving compressed gas. Once the large storage accumulator is filled, the smaller accumulator is filled and subsequently dumped during each pulse jet produced. Water is loaded into the water storage tube using compressed air at a reduced pressure as the rapid filling force. Once the gas accumulator and water tube are filled, valves V1, V2 and V3 are closed while valve V4 is opened. In this position, the system is ready for firing and requires only a trigger pulse to actuate the quick opening dump valve, V2. An air slug then forces the water out through the nozzle, typically 1" to 1-3/8" tip diameter with results similar to those discussed earlier in this report. By throttling the "one-shot" gas pressure, the system can be ranged to give the desired effects.

If it is desired to produce a continuous stream of water, throwing a control switch from "pulse" to "steady" engages a clutch between the motor and pump and disengages the compressor pump. The pump now forces water through a smaller nozzle at approximately 150 psi. This technique was found to be desirable while talking with several project personnel.

This system would be mounted on a single skid platform approximately six feet by six feet. The water storage capacity would be held to approximately 100 - 150 gallons which would be sufficient for approximately 100 separate pulses.



Suggested Pulsed and Continuous Water Cannon System

FIGURE 12

1. Pulse Jet Nozzle
2. Water Tank
3. Single Pulse Gas Accumulator
4. Compressed Gas Accumulator
5. Regulator for Pressurizing Water Tank
6. Regulator for Setting Single Pulse Gas Pressure
7. Compressor
8. Control Console
9. Clutch: Prime Mover to Compresser
10. Prime Mover
11. Clutch: Prime Mover to Pump
12. Water Pump
13. Water Column Overflow Line
14. Continuous Jet Nozzle - ½" Tip
15. Trigger

V1 Shut-off Control Valve - Large to Small Gas Accumulator

V2 Quick Opening Dump Valve

V3 Three-Way Water Valve - Tank to Water Tube or Pump

V4 Slide Valve for Pulse Jet Water Tube

V5 Water Tube Overflow Line - Shut-off Valve

FIGURE 12 (cont'd.)

CONCLUSIONS

All system goals were met resulting in a demonstration device clearly adaptable to humane crowd control.

The final water cannon system developed to demonstrate a pulsed jet's effectiveness fully met the goals set out at the beginning of the program. These included:

- A water jet pulse approximately twenty feet long with a volume of one to one and a half gallons.
- A jet range of approximately 150 feet.
- Long operational staying power as a result of water conservation.
- Gradual escalation of jet impact ranging from "rain" at 150 feet to "knock down" power at 50 feet.
- Simple control over jet pressure even at close range.
- Highly directional, off-on control.
- Non-toxic solution and easily "doped" with additives if desired.
- A completely useable force not merely a threat.